

Pilot Production of Biogas from Vegetable Waste for Energy Self-Sufficiency in Households in Ouagadougou Peri-Urban Area, Burkina Faso

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Abstract

Inadequate solid waste management, particularly organic waste from markets, represents a major environmental and health challenge at Ouagadougou in Burkina Faso. The aim of the study was to produce biogas from plant waste to achieve energy self-sufficiency in the Burkina Ouagadougou peri-urban areas. The methodology involves the collection and physicochemical characterization of vegetable waste. A 200-liter pilot biodigester equipped with a meter, a biogas storage chamber, and a stove designed by the Albert Schweitzer International Centre (CEAS) was used for the tests. Anaerobic digestion was carried out, including an acclimatization phase with cow manure alone, followed by the addition of different proportions of substrate (1/3, 1/2, and 3/4 after 24 hours of pre-fermentation). Anaerobic digestion was monitored in terms of the volume of biogas produced, its composition (CH₄, CO₂, H₂S), and changes in the pH and volatile fatty acids (VFA) of the digestate. The results of the physicochemical parameters show average contents of dry matter (DM) and volatile dry matter (VDM) of 6.20% and 78.88%, respectively. A C/N ratio of 5.47 was obtained, indicating an ideal substrate for biogas production. Cow manure alone generates the highest average volume of biogas (7.42 dm³/day), but co-digestion with vegetable waste significantly improves the quality of the biogas. An overall assessment of the digester’s performance shows good energy yield. The digestate pH remains stable (7.31 - 7.50), and H₂S levels are low (peaking at 37 ppm). Therefore, the technology is technically reliable, but its long-term productivity depends on proper operational management, particularly substrate supply.

Keywords

Vegetable Waste, Anaerobic Digestion, Biogas, Domestic Energy, Peri-Urban Area, Ouagadougou

1. Introduction

The city of Ouagadougou, capital of Burkina Faso, is undergoing rapid urbanization and sustained population growth, leading to an exponential increase in municipal solid waste production [1]. Within this waste stream, vegetables, mainly from households, markets and agri-food units, represent a significant and particularly problematic fraction [2]. Indeed, the current management of this bio-waste is largely deficient. According to the United Nations Environment Programme, the city's markets produce considerable volumes of waste every day, only a small proportion of which is collected and treated properly [3]. This situation has a negative impact on the environment and the population's health. The accumulation of this waste in the open air promotes the proliferation of disease vectors, odor pollution, and soil and water contamination by leachates. In addition, its uncontrolled anaerobic decomposition is a source of methane emissions, a powerful greenhouse gas [4] [5]. This dual health and environmental challenge is compounded by a serious energy problem. Indeed, as in other countries of the West African Economic and Monetary Union (WAEMU), access to modern energy in Burkina Faso remains limited, with a major dependence on traditional biomass such as firewood and charcoal, which accounts for 74% of national energy consumption according to Chitou and Gbandey [6]. The majority of the population (around 81%) still depends on wood energy (firewood and charcoal). In rural areas, almost all of the energy consumed comes from biomass. The national average is therefore 0.69 kg of firewood per person per day [7]. The vast majority of households use wood and charcoal for cooking, contributing to deforestation and air pollution. This dependence has negative health consequences, including water pollution and sanitation problems, and creates gender inequalities, as women are responsible for collecting wood. In the face of these challenges, waste recovery through anaerobic digestion appears to be a strategic approach, as it offers a simultaneous response to sanitation and energy access issues.

Globally, the high methanogenic potential of fruit and vegetable waste is well documented, with fruit and vegetable waste identified as the most wasted food category worldwide by Gustavsson *et al.* [8] and Bouzid *et al.* [9]. Biochemical characterization studies show that this waste is mainly composed of highly fermentable elements such as leaves and peelings [9]-[11], making it a substrate of choice for biogas production. In Burkina Faso, pioneering work has already demonstrated the technical feasibility of producing biogas from various local resources. This is particularly the case in the study conducted by Traoré *et al.* [12], which specifically assessed the biomethane potential of vegetable waste, confirming the interest in

this resource. The work of Makaya *et al.* [13] showed the possibility of optimizing biomethane production from vegetable waste from “yaars” and markets at Ouagadougou in Burkina Faso. An optimal yield of 3540 L CH₄/kg was obtained by Makaya *et al.* [13], demonstrating the high biomethanogenic potential of this vegetable waste from “yaars” and markets. Technology transfer could enable peri-urban households to produce energy to meet their energy needs. The objective of the study was to produce biogas from plant waste to achieve energy self-sufficiency in peri-urban areas of Burkina Faso.

2. Materials and Methods

2.1. Sampling and Preparation of Vegetable Waste

The vegetable waste samples were collected from two places in Ouagadougou, at the “Zongo” market (12°20'13.5"N, 1°35'45.4"W) and at the “Cit  An II” one (12°20'13.5"N, 1°35'45.4"W). A total of 200 kg of vegetable waste, corresponding to four 50 kg bags, was collected over a period of one week to ensure a constant supply during the tests. To meet one of the study’s objectives, which was to determine the physicochemical parameters of the samples, the vegetable waste (cabbage leaves) underwent pre-treatment followed by a series of analyses (Figure 1). The inoculum used to start the methanization process was fresh cattle manure. It is known for its richness in methanogenic microorganisms that promote the degradation of organic matter and the production of methane. The cattle manure was collected from local farmers located near the experimental site. The collected biomass was dried in the sun for several days and then ground to obtain a homogeneous and easily digestible material. The resulting ground material underwent 24 hours of pre-fermentation to trigger the biological processes.

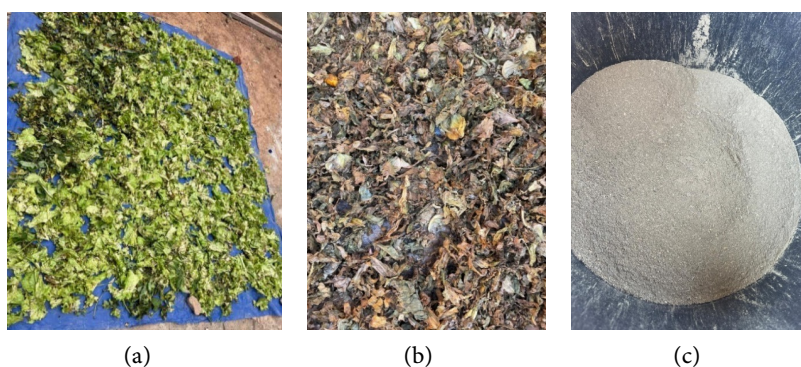


Figure 1. Preparation of waste samples: (a) fresh vegetable waste, (b) dried samples, (c) shredded vegetable waste.

2.2. Characterization of the Substrate

The physicochemical parameters of the vegetable waste powder (substrate) were analyzed using recognized methods to assess its biodegradation potential. The pH was measured according to the method of Nout *et al.* [14] on a sample homogenized with distilled water using a previously calibrated pH meter. The ashes were

obtained by incinerating the dry matter at 550 °C. The volatile dry matter was calculated by weighing the difference between the mass after passage through the oven and the mass of the waste calcined at 550 °C in the furnace, which also allowed the total carbon content to be estimated according to the theoretical VDM/TOC ratio, generally estimated at 1.74 [15]. Lipids were extracted using the Soxhlet method with hexane, followed by evaporation of the solvent and weighing after drying. Insoluble lignin was determined according to TAPPI 222 [16] after acid hydrolysis and vacuum filtration. Finally, the carbohydrate content was measured using the colorimetric method of Dubois *et al.* [17], involving a reaction with phenol and sulfuric acid before reading with a spectrophotometer.

2.3. Experimental Setup

The experiment was conducted using a batch-type pilot biodigester designed by the Albert Schweitzer Ecological Center (CEAS). The main reactor consists of a plastic barrel with a total volume of 200 L, sealed to ensure strict anaerobic conditions (Figure 2). An opening was made in the top of the barrel lid to serve as a feed pipe equipped with a valve, and another opening with a valve was made in the barrel to serve as a spillway. The barrel was hermetically sealed and glued to prevent any leaks. The digester is equipped with a barometer to measure the pressure inside the digester. The device is connected via a pipe equipped with valves to a J2.5 meter to quantify the gas produced, an air chamber to contain the gas produced, a furnace equipped with a gas burner, and a barometer to measure the pressure.

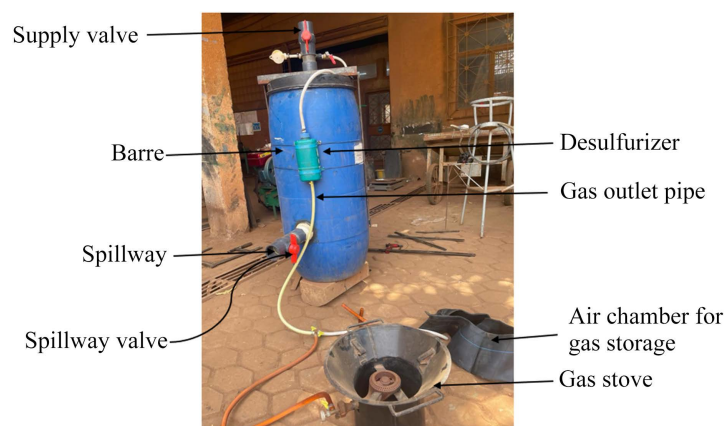


Figure 2. Biodigester and accessories.

2.4. Start-Up of the Biodigester

The reaction volume of the biodigester represents two-thirds of the barrel's volume. The digester was fed sequentially after two weeks of biogas production (Figure 3). The initial feed consisted solely of cattle manure diluted in water in equal proportions (1 kg of cattle manure in 1 liter of water). The mixture was introduced into the digester through the feed pipe equipped with a safety valve, ensuring efficient feeding of the hermetically sealed barrel. After each substrate depletion

marked by a drop in biogas production, a new substrate pre-fermented at 2% (m/v) was added successively to 1/3, 1/2, and 3/4 of the reaction volume.



Figure 3. Digester feed-digester emptying.

2.5. Monitoring of Anaerobic Digestion

A Direct Soil pH meter, equipped with an electrode whose probe is immersed in a KCl solution, was used to monitor the pH and temperature during anaerobic digestion. The gas produced was monitored using the GEMBIO biogas analyzer. This device measures the content of the various components of biogas, namely methane (CH₄), carbon dioxide (CO₂), and hydrogen sulfide (H₂S). The cumulative volume of biogas was measured continuously using a gas meter (**Figure 4(d)**). The volume produced between two readings was calculated as the difference between the final and initial volumes.

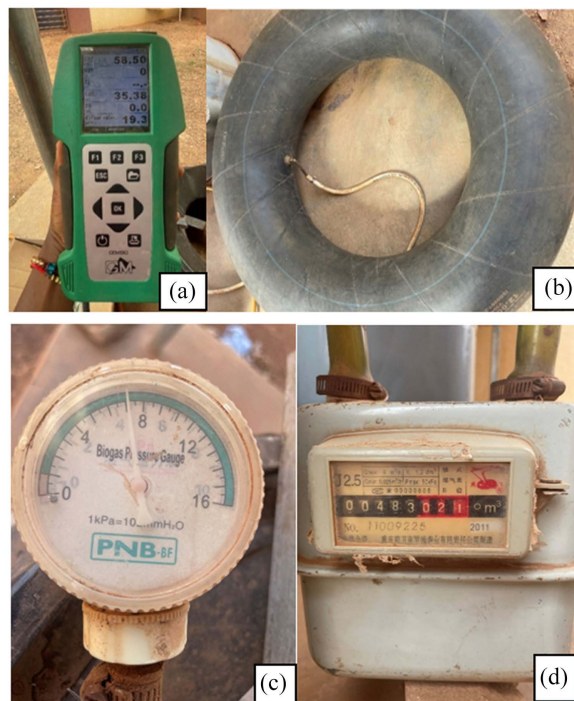


Figure 4. Biogas analysis equipment. Legend: (a) GEMBIO biogas analyzer; (b) air chamber for biogas storage; (c) barometer; (d) gas meter.

The gas produced is stored in the air chamber (**Figure 4(b)**). Periodic analyses were performed using the GEMBIO analyzer to determine the CH₄, CO₂, and H₂S content (**Figure 4(a)**). The barometer was used to measure the pressure in the digester (**Figure 4(c)**).

2.6. Monitoring Parameters during Anaerobic Digestion

■ pH

A Direct Soil pH meter, equipped with an electrode whose probe is immersed in a KCl solution, was used to measure the pH and temperature of the pre-fermented substrate and digestate.

■ Volatile Fatty Acids (VFA)

Each time the tank was emptied, a quantity of digestate was taken and stored in the freezer for volatile fatty acid analysis. The measurement was carried out using a 25 mL supernatant taken after agitation. The initial pH was measured, then the mixture was acidified with sulfuric acid (H₂SO₄ at 0.1 mol/L) until a pH of 4 was reached (volume noted as V_1). The solution was then boiled for 3 minutes and cooled. Neutralization was then carried out using a sodium carbonate solution (Na₂CO₃ at 0.05 mol/L) to a pH of 7 (volume noted as V_2). The VFA concentration was calculated using the following formula:

$$\text{AGV (g/L)} = 6 \times 10^4 \times ((C_2 \times V_2) / E)$$

where:

- C_2 : concentration of Na₂CO₃ (mol/L);
- V_2 : volume of Na₂CO₃ added (L);
- E : sample volume (mL).

2.7. Data Analysis

Data entry, means, and standard deviations were calculated using Excel 2016. Standard deviation measures the variability of observations. The effect of time on daily biogas production and its components (CO₂, H₂S, CH₄) was assessed using a mixed linear model that took into account the temporal dependence of repeated measurements. STATA 2017 and Python 3.2 analysis software were used.

3. Results

3.1. Physicochemical Parameters of Vegetable Waste

Table 1 shows the results of physicochemical analyses of the substrate. The relatively low dry matter content (6.20%) indicates a high moisture content that promotes microbial activity. The ash content of 16.23% corresponds to the mineral fraction of the substrate. The volatile dry matter content of 78.88% indicates the organic fraction of the substrate, which is essential for biogas production. A high percentage is favorable for biodegradation. The total carbon content of 45.34% shows a high concentration of organic carbon, a key parameter for fermentation and methane production. The total nitrogen content of 8.28 mg/g influences the

C/N ratio and the availability of nutrients for the microorganisms responsible for biodigestion. Lipids, at a moderate concentration (3.58%), can influence the process by providing a source of energy. Lignin (13.5%) is a complex compound that is difficult to degrade; a high content can limit the biodegradability of the substrate and require pre-treatment. The C/N ratio is relatively low (5.47), which could indicate an excess of nitrogen, requiring adjustment of the substrate to optimize biogas production.

Table 1. Physicochemical parameters of the substrate.

Parameter	Unit	Average Values
Dry matter	%	6.20 ± 0.49
Total ash	%	16.23 ± 0.17
Volatile dry matter	%	78.88 ± 0.37
Total carbon	%	45.34 ± 0.21
Total nitrogen	mg/g	8.28
C/N ratio	-	5.47
Lipid	%	3.58 ± 0.33
Lignin	%	13.5

3.2. Evaluation of Biogas Productivity and Quality

■ Physicochemical Parameters of Digestate

Table 2 shows the results of analyses of the physicochemical parameters of the digestate. Manure has a lower dry matter content (91.71) than the others. Ash represents the amount of mineral matter present after incineration. A low ash content, such as that found in feeds 1/3, 1/2, and 3/4, indicates a higher proportion of organic matter that is likely to be degraded during anaerobic digestion. Volatile dry matter (VDM) and total carbon (TOC) indicate the organic fraction of the substrate, which is essential for biogas production. A decrease in values in the different proportions of the substrate compared to manure. Volatile fatty acids (VFAs) are by-products of organic degradation and influence the efficiency of the anaerobic digestion process. Too high a concentration can inhibit methane production. The 1/3 substrate feed has the highest concentration of VFA, which can influence its biodegradability. A stable pH between 6.5 and 7.5 is optimal for anaerobic digestion. All the pH values in this table are within the range that is considered to be good. An increase in the substrate feed ratio of 3:4 could indicate an advanced digestion process or weaker acidification.

Table 2. Physicochemical parameters of digestate.

Sample	pH	Dry Matter (%)	Total Ash (%)	Volatile Dry Matter (%)	Total Carbon (%)	Volatile Fatty Acids (mg/L)
Cow manure (CM)	7.31	91.71 ± 0.27	2.45 ± 0.06	5.85 ± 0.21	3.36 ± 0.12	96.00

Continued

CM + 1/3 of substrate (v/v)	7.34	96.54 ± 0.42	1.13 ± 0.12	2.33 ± 0.29	1.34 ± 0.17	132.00
CM + 1/2 of substrate (v/v)	7.42	99.36 ± 0.06	0.27 ± 0.02	0.37 ± 0.04	0.21 ± 0.02	84.00
CM + 3/4 of substrate (v/v)	7.50	99.28 ± 0.01	0.31 ± 0.01	0.40 ± 0.003	0.23 ± 0.001	39.60

■ Biogas Volume Produced over Time

The production of biogas was monitored under four conditions: manure alone (at start-up) and three increasing proportions of vegetable waste (1/3, 1/2, and 3/4). **Figure 5** shows the volume of biogas produced during our experiment. It allowed us to assess the volume of biogas produced by our four feedings. Cow manure alone generated the highest average volume of biogas (7.42 dm³/day). The gradual introduction of vegetable waste led to a decrease in the total daily volume of biogas. When the ratio was 1:2, the average daily biogas production was 5.42 dm³/day. The 1:3 ratio feed curve shows that biogas production stabilizes at 3 dm³ from the fifth to the ninth day.

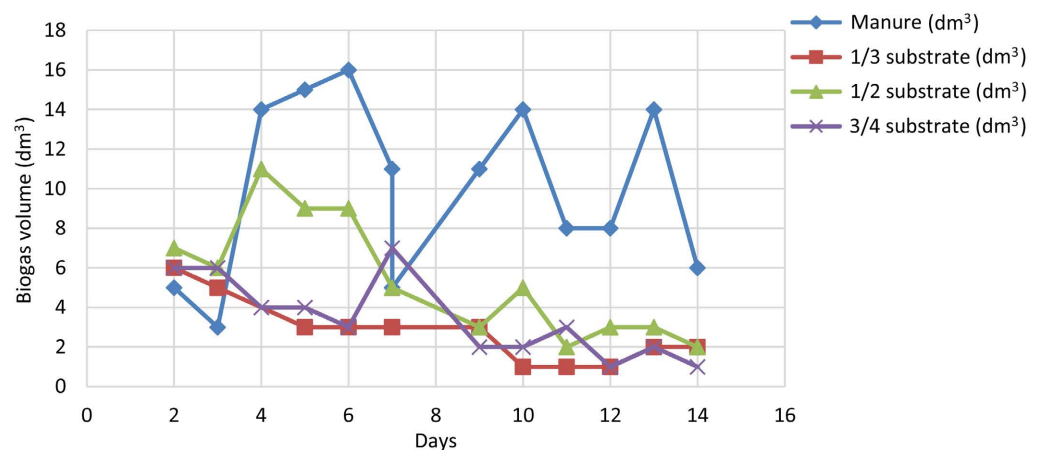


Figure 5. Change in the quantity of biogas.

3.3. Quality of Biogas Produced over Time

■ Monitoring of Methane Content

As illustrated in **Figure 6(a)**, there has been a notable evolution in the methane content. Following the commencement of methane production, the manure feed curve demonstrates a substantial increase, reaching 57% from the sixth day onwards. From the thirteenth day onwards, the process stabilizes until the end of production. The incorporation of vegetable waste had a highly beneficial effect on the quality of the biogas. The curve representing the methane content of the feed at one-third of the substrate is shown in orange. It is characterized by an initial methane content that exceeds that of manure alone, suggesting an enhancement in methane content through co-digestion. The content rises rapidly and reaches

approximately 60% from the ninth day onwards before stabilizing. The feed at half of the substrate, as shown by the grey curve, demonstrates a rapid and significant increase, reaching almost 70% in less than 10 days. Following this growth phase, the next stage is to stabilize at this high content level. This biogas content is considered to be of very good quality. Finally, feeding with 3:4 of the substrate (yellow curve) increased to reach a peak of around 67% after six days. Following this peak, production stabilizes until the end of the process. The observed decline in CH₄ production may be attributable to the depletion of the substrate available to methanogenic bacteria. **Figure 6(b)** shows the evolution of the carbon dioxide content, which has a generally opposite trend to that of methane. The manure curve starts with a relatively low percentage of CO₂, then increases to around 46%, before decreasing again to stabilize at around 40%. The curve representing 1:3 of the substrate shows initial variations. It starts at its peak at 40%, decreases, and then stabilizes. The grey curve starts at a much higher percentage than the manure curve, which has a substrate ratio of 1:2. The manure curve also has a substrate ratio of 1:3. It quickly reaches its highest point at 61% before dropping significantly to reach the lowest content of the entire production. The curve for the 3:4 ratio of substrate starts at 60% and then quickly goes down to around 30% before it starts to stabilize. **Figure 6** shows the total amount of CO₂ and CH₄ produced during anaerobic digestion. It shows a big drop in CO₂ levels during the 15 days of incubation, along with a rise in CH₄ levels, suggesting that CO₂ is being turned into CH₄. Studies have shown that hydrogenotrophic methanogenic bacteria use molecular hydrogen to reduce CO₂ to CH₄ [18] [19].

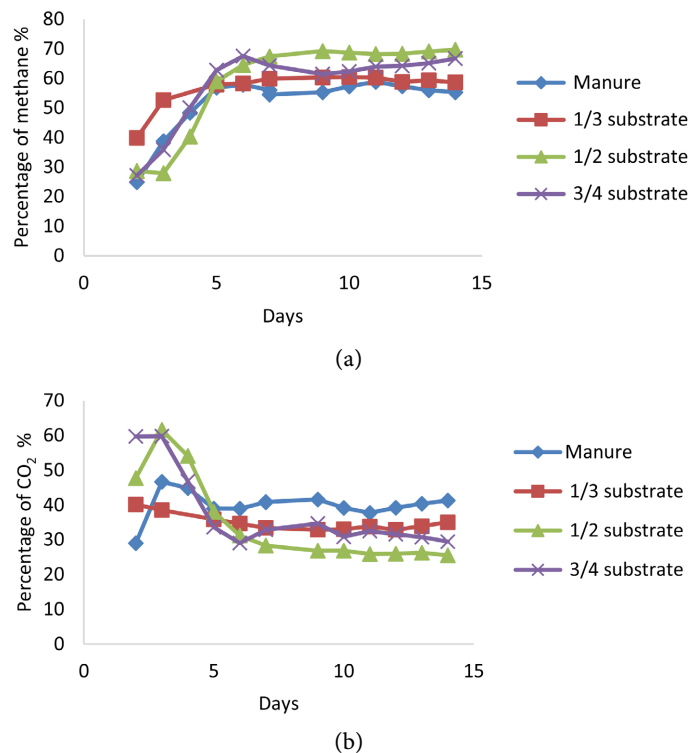


Figure 6. Change in (a) methane and (b) carbon dioxide content.

■ Monitoring of Hydrogen Sulfide Content

Figure 7 shows the hydrogen sulfide content in biogas during experiments. Unlike the other graphs, the hydrogen sulfide concentration remained at very low levels for all feeds (maximum average of 9 ppm), preventing equipment corrosion and toxicity problems for the microbial consortium. The blue curve representing manure starts at zero and increases slightly to reach its peak at 12 ppm before falling back to zero. The red curve representing the 1/3 substrate feed starts with a peak at 4 ppm, decreases, and then falls back to zero after 5 days. The gray curve initially fluctuates with a peak at around 27 ppm, then decreases sharply and then disappears. The curve for 3/4 of the substrate starts slightly higher than all the others, with a peak at around 37 ppm, then decreases considerably and disappears around the ninth day.

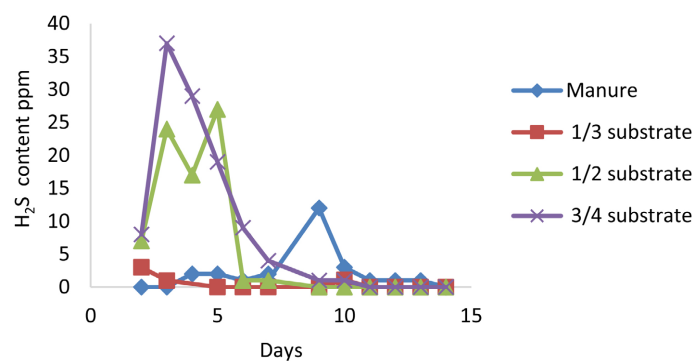


Figure 7. Evolution of hydrogen sulfide content.

■ General Trend in Pilot Biogas Production

The evolution of methane (CH_4) shows a latency period from day 0 to day 1 (**Figure 8**). From day 1 to day 3, there is a start-up period for CH_4 production, which increases from 25% to 48%. From day 4 to day 12, the CH_4 content reaches 55% and rises to 59%. From day 13 to day 20, there is a slight decrease in bio-methane, which falls to 52%. CO_2 evolves inversely to CH_4 , which is normal with an initial peak at 46% (day 2) due to high acid production. CO_2 then stabilizes between 40% - 44% with a slight increase around day 18 - day 20. The hydrogen sulfide (H_2S) content is low at the start (0% - 2%). The significant peak occurs around day 8 (~12%).

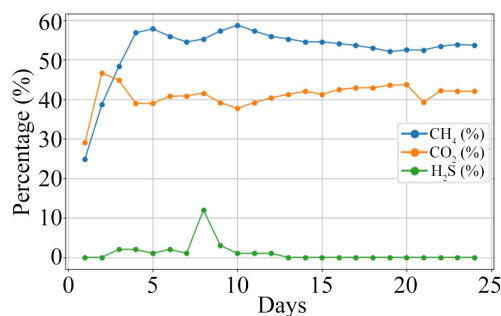


Figure 8. Evolution of pilot biogas production.

4. Discussion

The physicochemical analysis of vegetable waste revealed a volatile dry matter (VDM) content of 78.88%, reflecting a high proportion of biodegradable organic matter, which is essential for good methanogenic potential according to Nikiema [20] and Deublein and Steinhauser [21]. The C/N ratio was 5.47, which is below the optimal range of 20 - 30 generally recommended for stable and efficient anaerobic methanogenesis [22] [23]. Such a low C/N ratio, typical of nitrogen-rich vegetable waste, can potentially lead to an accumulation of ammonia ($\text{NH}_3/\text{NH}_4^+$) in the digester, inhibiting the activity of methanogenic bacteria, particularly at higher pH levels [24]-[26]. This result highlights the strategic importance of co-digestion with more carbon-rich substrates such as cattle manure, which was used in our study as inoculum and initial co-substrate to balance this ratio and prevent inhibition [27]. The lignin content was moderate. Excessive lignin content could have limited biodegradability and hydrolysis rate [28] [29], but the value obtained is considered acceptable for the process. In summary, the physicochemical parameters showed that vegetable waste can be considered a good candidate for bio-methane production.

The biogas production results show that feeding only cattle manure generated the highest volume of biogas (7.42 dm³/day, with a peak of 16 dm³). The introduction of vegetable waste led to a decrease in the total volume of biogas produced. This could be explained by the difficulty of anaerobic digestion microorganisms to adapt. According to Taherzadeh and Karimi [30], anaerobic digestion microorganisms need time to acclimatize to a new substrate. The quality of the biogas in terms of methane content was significantly improved by co-digestion, reaching proportions of 70%, which is much higher than that of manure alone (52.71%). Our results on methane proportions are consistent with those reported in other studies on the methanization of household vegetable waste, which often range between 50% and 70% [31]-[33]. This improvement in methane quality, despite a sometimes-lower total volume of biogas, indicates the high intrinsic methanogenic potential of vegetable waste. The decrease in overall biogas volume with the addition of vegetable waste could be partly due to the low C/N ratio of vegetable waste. According to Li *et al.* [34], the C/N ratio corresponds to the degree of mineralization of organic matter. In fact, the higher the nitrogen content, the lower the ratio and the higher the rate of mineralization. Too low a value leads to an accumulation of ammonia and pH levels exceeding 8.5, which are toxic to methanogenic bacteria. It is already known that optimal anaerobic digestion occurs for C/N ratios between 20 and 30. For higher values, nitrogen consumption is rapid, leading to low biogas production. Furthermore, the change in CO₂ content showed a generally opposite trend to that of methane, which is an expected characteristic of the methanization process [21]. Successful methanization depends on maintaining stable conditions.

With regard to the digestate, the pH remained remarkably stable and within a favorable range (6.5 - 7.50) for all feedstocks. This range is considered optimal for

the activity of the microbial consortia involved in methanogenesis [35] [36].

The stability of the pH, despite the gradual introduction of vegetable waste that can potentially acidify the environment during acidogenesis, shows a good buffering capacity of the system, probably conferred by the bovine manure inoculum and the production of bicarbonates during anaerobic degradation [37] [38].

Volatile fatty acid (VFA) concentrations varied, with the highest value (132 mg/L acetic acid) for the 1/3 substrate feed, decreasing for the 1/2 (84 mg/L) and 3/4 (39.60 mg/L) proportions. Very high VFA levels (>2000 - 3000 mg/L) may indicate an imbalance in the process and inhibition of methanogenesis [39]-[41]. The VFA levels observed, coupled with stable pH and better methane production, suggest active hydrolysis and acidogenesis, followed by efficient methanogenesis, particularly for the 1/2 and 3/4 proportions, where VFA levels are lower, indicating good conversion. Franke-Whittle *et al.* [42] showed that at stable pH, the quality of VFA has more or less impact on methanogenesis: an acetate concentration of 2400 mg/L still has no effect on methanogenic bacteria, while a propionate concentration of 900 mg/L is sufficient to inhibit them in part. Finally, the H₂S content remained very low for all feeds (maximum peak of 37 ppm for the three-quarter [3/4] feed and highest average of 9 ppm for the same feed). High concentrations of H₂S (>50 - 100 ppm in biogas) can be corrosive to equipment and toxic to methanogens [25] [43]. H₂S gas has a rotten egg smell, detectable by humans from 0.21 ppmv according to Izumi *et al.* [44]. Prolonged inhalation of H₂S causes irritation of the mucous membranes of the eyes and respiratory tract, effects on the central nervous system, respiratory and cardiac disorders, and can lead to death [45] [46]. H₂S is also corrosive to most metals and can therefore damage biogas recovery equipment. H₂S must therefore not be released into the atmosphere. However, this is very rarely the case because biogas undergoes combustion in order to be recovered. During combustion, H₂S is oxidized to form sulfur dioxide (SO₂), which is also toxic. According to Panza and Belgiorno [47], engines are more sensitive than turbines to H₂S, whose concentration must not exceed 500 ppmv, or even 50 ppmv depending on the type. The low levels observed are therefore a major advantage for future exploitation of the biogas produced.

The overall evolution of biogas production using this technology shows a latency period from D0 to D1 for biomethane (CH₄). From D1 to D3, there is a start-up period for CH₄ production, which increases from 25% to 48%. This indicates a gradual establishment of methanogenic bacteria in the biodigester. The digester leaves the strictly acidogenic phase and stabilizes after 4 days. According to Elasri and El Afilal [48], anaerobic digestion occurs in 4 stages, the first of which is the hydrolysis of organic matter such as proteins, fats, cellulose, and starch. This stage releases monomers such as amino acids, fatty acids, and simple sugars. These monomers are converted into a mixture of lactic acid, butyric acid, etc., and neutral compounds (ethanol) by acidogenic bacteria, thus acidifying the digester. Stabilization occurs when the various acids and other products from the previous stage are converted into methane precursors such as acetic acid, carbon dioxide

(CO₂), and hydrogen (H₂). This is the work of acetogenic bacteria. From D4 to D12, the CH₄ content reaches 55% and rises to 59%. A period of stabilization of the digester is observed, with a level typical of a digester in good working order with dominant methanogenic activity. In this phase, methanogenic bacteria use the precursors formed in the previous stages to produce methane. The four stages take place simultaneously in the digester, with a balance being established between the stages. From D13 to D20, there is a slight decrease in biomethane, which falls to 52%. This imbalance is thought to be due to substrate depletion. The lack of renewal leads to the end of production between the 21st and 24th day. This shows the need for continuous feeding of the digester, especially from the 12th day onwards, when an equilibrium is observed in the digester with a biomethane content reaching 59%.

CO₂ evolves inversely to CH₄, which is normal with an initial peak at 46% (day 2) due to high acid production. CO₂ then stabilizes between 40% - 44% with a slight increase around D18 - D20. This result is consistent with the work of Nikiema *et al.* [49], as at the start of anaerobic digestion, organic matter is broken down with the release of large amounts of CO₂. As methanization progresses, CO₂ is consumed and used in the production of CH₄ via the hydrogenotrophic pathway. The hydrogen sulfide (H₂S) content is low at the outset (0% - 2%). The peak occurs around day 8 (~12%), indicating the degradation of sulfur-rich materials (proteins, food waste) and high activity of sulfate-reducing bacteria. A rapid drop was observed after day 9, close to 0%. This is a very good sign, indicating a balanced system, as the available sulfur has been consumed. The methanogens have regained the upper hand.

5. Conclusion

This study addressed the issue of energy self-sufficiency among households in the peri-urban areas of Ouagadougou. The results confirm that vegetable waste could be an ideal substrate for biogas production, given its availability in our study area. However, this waste has a low C/N ratio (5.47), which proved to be a constraint for optimal volumetric production. The experiment showed that while cattle manure alone produced a higher volume of biogas, co-digestion with vegetable waste improved the quality of the gas, with a methane content reaching 58.41% (compared to 52.71% for manure alone), validating the hypothesis that biogas produced from vegetable waste has a high methane content. The biogas production technology proved to be biologically stable, efficient, and well-balanced. Methane levels reached values typical of an optimally functioning digester, confirming effective conversion of organic matter into biogas. The temporary rise in H₂S and its subsequent decline further demonstrate a healthy microbial succession and system recovery. The reduction in methane after day 12 highlights the need for continuous or periodic feeding to maintain performance. Therefore, the technology is technically reliable, but its long-term productivity depends on proper operational management, particularly substrate supply.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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